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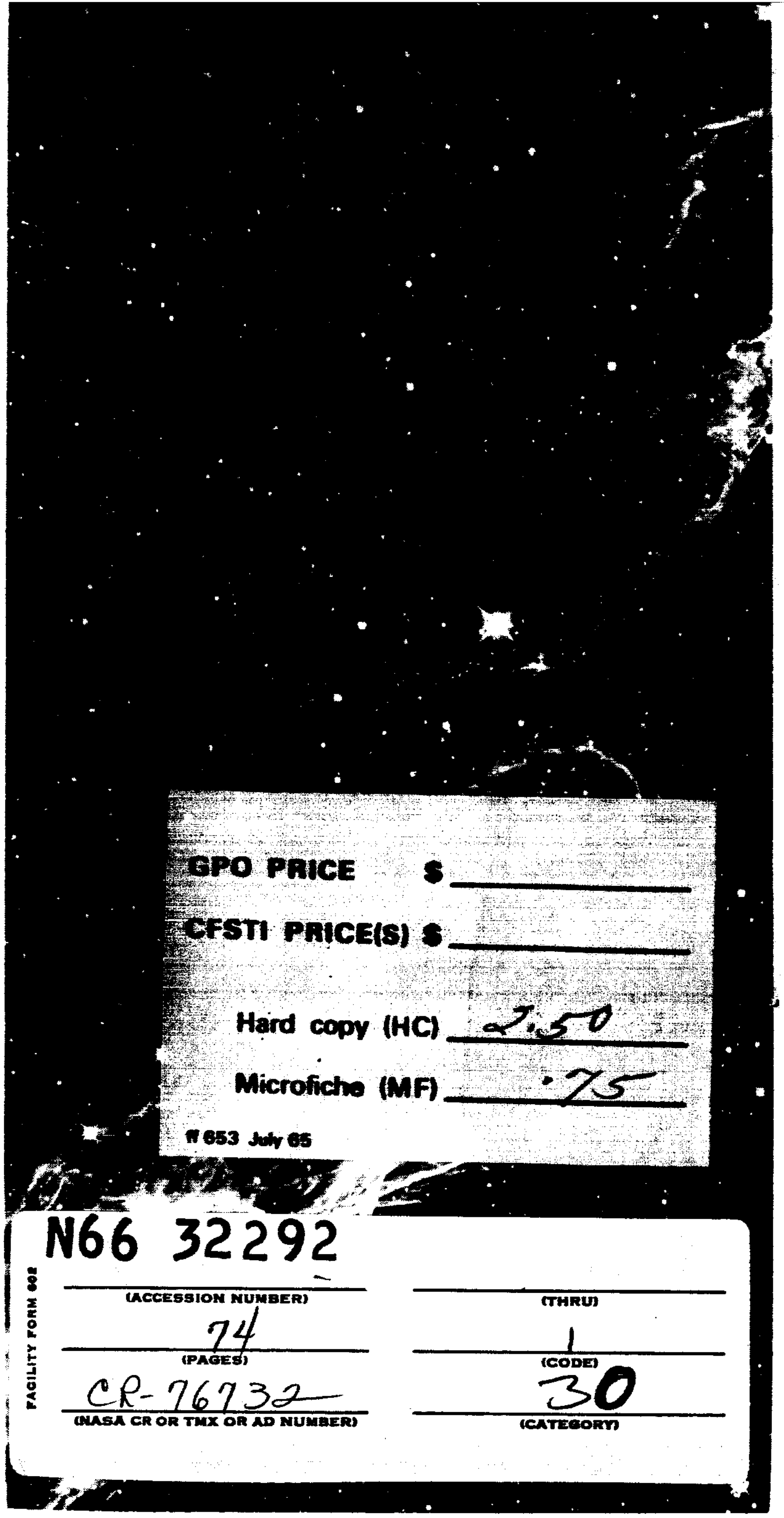

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Report A-3

THIRD ANNUAL SUMMARY REPORT

Report A-3

THIRD ANNUAL SUMMARY REPORT

by

Astro Sciences Center
of
IIT Research Institute
Chicago, Illinois

N66 32292

for

Lunar and Planetary Programs
Office of Space Science and Applications
NASA Headquarters
Washington, D. C.

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APPROVED:

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Astro Sciences Center

June 1966

FOREWORD

This annual report summarizes the reports published and the special tasks performed by the Astro Sciences Center of IIT Research Institute during the 12 month period from July 1965 to June 1966. A total of eighteen reports or technical memoranda are summarized together with a description of technical notes on which formal reports have not been written. The work has been performed under NASA Contract NASr-65(06).

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THIRD ANNUAL SUMMARY REPORT

1. INTRODUCTION

The Astro Sciences Center of IIT Research Institute (ASC/IITRI) has been engaged in a continuing program of research, study, and analysis for the Lunar and Planetary Programs Division under Contract No. NASr-65(06). This program was initiated on March 1, 1963 and has been renewed on December 1, 1963, January 1, 1965 and November 1, 1965. The first annual summary report, A-1, presented the accomplishments of work performed to September 1964, the second, A-2, presented the accomplishments of work performed to July 1965. This report covers the period from July 1965 to June 1966 during which 144 man months of effort were expended.

The program has provided technical information, data and methodologies, of an appropriate depth and breadth, in support of the planning requirements of the NASA. The areas of study necessary to meet the broad objectives of planning support are defined in the contract as:

a. Evaluation of methods for estimating the cost of future spacecraft.

b. Analyses of mission requirements for exploration of the solar system.

c. Determination of probability of mission success by analysis and evaluation of existing and planned launch vehicles, spacecraft maneuvers for various missions, and reliability of spacecraft systems and subsystems.

d. Re-evaluation of the scientific objectives and key elements of a long-range plan for the manned and unmanned exploration of the solar system.

While the ongoing activities of ASC/IITRI are reported to Lunar and Planetary Programs Division in monthly progress reports and at regularly scheduled review and planning meetings the more tangible output is in the form of technical reports. For the 12 month period reported here a total of 25 reports and documents have been submitted. Of these 13 will be included in Scientific and Technical Aerospace Reports (STAR). Summaries of these reports and of five technical memoranda are given in Section 2. Section 3 summarizes technical notes that have been performed but for which no formal reports have been written. Section 4 outlines the efforts on two special studies which have been undertaken by ASC/IITRI. Section 5 lists the papers published and presented as a result of work performed under this contract. Finally Section 6 is a bibliography of the reports and technical memoranda published under this contract since its inception.

2. SUMMARY OF REPORTS PUBLISHED JULY 1965-JUNE 1966

The four study areas listed above have been subdivided into subject categories. All reports are identified by the code letter, indicating technical areas, and by a sequential number reflecting the order of submission.

The eight report categories are as follows:

- A - Annual Summary Reports
- C - Cost Estimation Methods
- M - Mission Programming
- P - Objectives of Advanced Missions
- R - Success Probability Determinations
- S - Spacecraft Technology
- T - General Trajectory Studies
- W - Project Scheduling

An individual document in each of these categories may be published as a report, a digest report or a technical memorandum. Reports present the results of major studies, digest reports are summaries or condensations of reports, and technical memoranda include the results of studies in narrow technical areas, interim reports and other documents involving very limited distribution. These report types are discussed together with the distribution lists in Appendix 1.

2.1 Reports

Report C-6

"Spacecraft Cost Estimation"

W. P. Finnegan and C. A. Stone

May 1966

Reliable cost estimates of future space programs are needed to select optimum space exploration plans for program approval and for satisfactory budgeting and management. This study was undertaken to establish the relative cost significance of spacecraft subsystems and to further investigate the accuracy of a linear model for predicting future spacecraft costs.

As a result of this investigation, the relative cost significance of the spacecraft subsystems in a linear regression model was established. Telecommunications and data handling is the most important single factor, but structure and propulsion are also significant. Based on this analysis, an improved cost estimation equation was developed. Errors of 50% or less with 90% probability and errors of 25% or less with 60% probability can be expected. The model can easily provide cost estimates for long-range planning purposes by using program level information; it can also serve as a check on more detailed estimates.

This cost estimation equation, as well as previous editions, was developed to predict only the cost related to fabricating a spacecraft with its scientific payload. The equation does not predict costs related to launch vehicles, operational support, mission ground support equipment, and data analysis; nevertheless, it can be coupled with proven estimation techniques for such categories to provide total cost estimates for future programs.

Once total cost estimates are established, they can be utilized to determine the cost-effectiveness of future missions, and long-range planners can evaluate the mix of missions for the exploration of space within given budget constraints. In addition, these total cost estimates can provide reasonable estimates for budget requirements and, when used in conjunction with cost profile techniques, permit cost planners to budget individual program costs on a yearly basis.

Report C-7

"Spacecraft Program Cost Estimating Manual"

W. P. Finnegan and C. A. Stone

May 1966

An equation for estimating program costs for design, development and manufacture of spacecraft has been empirically developed based on the number of complete spacecraft (full prototypes, flight spares and flight models) and the weights of three spacecraft subsystems (telecommunications and data handling, structure, and propulsion). The accuracy of prediction is, of course, in part dependent upon the quality of the input data but root mean square errors of less than ± 30 percent have been demonstrated using program level information. Details concerning the development of the model, relative significance of the subsystems, programs on which the model is based, etc., are contained in ASC/IITRI reports (Beverly and Stone 1964*, Finnegan and Stone 1966**) for the Lunar and Planetary Programs Office, OSSA.

The cost estimation method is intended for use in long range planning and this report summarizes definitions, presents examples and supplies graphical aids for utilizing the equation developed.

*Beverly, J. E. and C. A. Stone, 1964, Progress on Spacecraft Cost Estimation Studies, ASC/IITRI Report C-4.

**Finnegan, W. P. and C. A. Stone, 1966, Spacecraft Cost Estimation, ASC/IITRI Report No. C-6.

Report M-9

"Missions to the Comets"

F. Narin, D L. Roberts, and P. M. Pierce

December 1965 NASA STAR N66-15978

This report is a digest of six Astro Sciences Center/ IIT Research Institute reports covering the general area of preliminary selection and assessment of missions to comets in the years 1965-1986. These reports consider the feasibility of unmanned scientific missions to well-known short-period comets and to new comets. These reports lead to the following conclusions. Opportunities for missions to short-period comets occur at an average rate of one per year; about one in four of these is particularly attractive. If a comet detection network and a quick-response launch facility are available in the future, nearly one new comet mission per year would be feasible. In most cases a launch vehicle of the Atlas-Centaur class would be adequate. For almost all missions the fundamental experiments would be measurements of charged particles, dust, and magnetic field in the comet coma and tail, together with measurements aimed at determining the properties of the comet nucleus. For more detailed treatment of comet missions the reader is referred to our Reports No. M-7, P-3, P-9, T-7, T-11 and T-13.

Report M-11

"A Survey of Missions to Saturn, Uranus, Neptune and Pluto"

P. Dickerman, A. Friedlander, F. Narin, J. C. Niehoff, P. M. Pierce, D. L. Roberts, M. Stein

June 1966 (in publication)

A survey has been conducted of missions to Saturn, Uranus, Neptune and Pluto. Because these planets are so different from the more familiar terrestrial planets such missions will be of considerable scientific interest. The data obtained, particularly the atmospheric composition, heat balance and internal structure data, will throw significant light on the origin and evolution of the planetary system as well as be of interest per se. A direct ballistic mode of flight appears to be satisfactory for loose planetary orbiters, except for Pluto. Flight times range from 2.5 to 10 years for 600 to 2000 lb loose orbiters to Saturn, Uranus and Neptune. A gravity assist mode of flight should be used, in years when it is possible, for flyby missions. The next launch opportunities for some gravity assist missions are:

Earth/Jupiter/Saturn	1976-1978, then in 1996
Earth/Jupiter/Uranus	1978-1980, then in 1992
Earth/Jupiter/Neptune	1979-1981, then in 1992
Earth/Jupiter/Pluto	1976-1978, then in 1989

In years when gravity assist is not possible, or if the guidance requirements are too high for gravity assisted flights, direct ballistic flights will be satisfactory. For near planet circular orbiters a nuclear electric low thrust mission mode becomes attractive. Missions to each of the planets are quite similar; a basic science payload of 85 lb and total payload of the order of 1000 lb can be used for all the planets. The power requirements can be satisfied with an RTG supply of less than 100 watts of useful power. A bit rate of 20 bits/sec and the antenna diameter of no more than 15 feet appears satisfactory. The guidance requirements for direct flyby flights appears to be well within the state of the art; for initial flyby flights a miss distance of 3 or more planet radii, with an uncertainty of 1 planet radius, appears to be satisfactory. Guidance requirements for gravity assist flights may be quite stringent. Both flyby and orbiter missions should be performed, followed by atmospheric probes and perhaps landers. An extensive program of flyby flights is not recommended, because the data attainable from flyby missions is limited in comparison to that provided by orbiters.

Report M-12

"A Survey of Multiple Missions Using Gravity-Assisted Trajectories"

J. C. Niehoff

April 1966

Over the past several years a number of general studies have been performed to investigate the advantages of gravity-assisted trajectories in solar system exploration. Results of these studies continue to indicate some significant improvements over direct trajectories. Very few studies, however, have been concerned with the practical application of gravity assist to specific missions.

Thus the objectives of this survey were to briefly analyze gravity-assisted multiple missions to a number of specific solar system targets and to recommend for further analysis those missions that have practical advantages over direct missions to the same targets. The scope of the survey included Venus-assisted missions to Mercury, several outer-planet gravity-assisted missions, out-of-the-ecliptic missions, solar probes, reconnaissance (Earth return) missions, gravity assist to the asteroids (as a group and individually), and comet rendezvous missions. In addition, satellite gravity assist for orbital maneuvers was assessed.

Six recommended multiple missions are reviewed in the summary table. The Earth-Venus-Mercury mission has already received some attention. Recent trajectory studies indicate,

SUMMARY OF MULTIPLE MISSIONS RECOMMENDED FOR FURTHER STUDY

Mission	Launch Opportunities	Principal Objectives	Advantages over a Direct Mission	Ideal Velocity, ft/sec	Trip Time
Earth-Venus-Mercury	1970 and 1973	Surface temperature and magnetic field measurement, atmosphere investigation (by occultation and Venus drop sonde), and mass determinations.	Improved payload and multiple objectives	43,000	175^d
Earth-Jupiter-Saturn-Uranus-Neptune	1977 or 1978	Combined investigation of all outer-planet (except Pluto) atmospheres and magnetic fields.	Better spacecraft utilization and reduced flight time to Neptune	55,000	8.6^y
Earth-Jupiter-90° Out-of-the-Ecliptic	Once every 13 months	Investigation of interplanetary medium at all solar latitudes (solar probe or Earth recovery objectives may be added).	Significantly reduced energy requirements	56,000	$3.5\text{-}4.0^y$
Earth-Venus (single or multiple)-solar probe	Once every 19 months	Investigation of solar corona to 0.1 AU combined with Venus flyby objectives. Also, solar surface astronomy at extremely low scan rates.	Improved perihelion reduction and multiple objectives	$<$65,000	$<2.0^y$
Earth-Jupiter-solar probe	Once every 13 months	Investigation of solar corona between 0.1 AU and apparent solar surface.	Significantly reduced energy requirements	56,000	2.5^y
Earth-Mars-asteroid fly-through	Once every 26 months	Deep space flight test (including gravity assist) of precursor spacecraft to outer planets and assessment of asteroid hazards.	Increased asteroid belt penetration and inclusion of a gravity-assist maneuver	$<$46,500	$<3.0^y$

however, that only two good opportunities for such a mission exist between now and 1981. Further study is recommended to determine the constraints imposed by this mission on a Venus flyby in 1970 or 1973, especially if Venus drop sondes for atmospheric experiments are planned.

Detailed gravity-assist outer-planet mission studies are needed soon. Advanced planning of planetary exploration indicates that the first extensive use of gravity-assisted trajectories will be made for these missions. Study of the Earth-Jupiter-Saturn-Uranus-Neptune "Grand Tour" is recommended since it typifies these missions.

Moderate-energy, 90° out-of-the-ecliptic missions with a Jupiter assist will provide interplanetary data at all solar latitudes. A study of the practical value of this mission is recommended as a secondary objective to early Jupiter flybys. Additional objectives for similar follow-on missions should also be evaluated.

Solar probes down to 0.1 AU using single or multiple Venus assists combine a number of useful objectives into one mission. For further reductions in perihelia, Jupiter assists are recommended. Mission studies should focus on spacecraft design problems due to large environment variations between 5 AU and the solar surface.

Finally, as a precursor mission to outer-planet exploration, a Mars-assisted asteroid fly-through is recommended.

Attention to development time and the practicality of such a test flight are needed.

In addition to the specific areas of analysis suggested for each of these missions general problems concerning spacecraft design constraints, encounter profiles, guidance and control requirements, and launch window definition should be considered. Two multiple missions are not suggested for further consideration at this time: rendezvous missions (low hyperbolic approach velocities, VHP) to individual asteroids or to the comets in which Mars or Jupiter gravity assist is used. Instead, further analysis of non-minimum energy direct trajectories with minimized VHPs is needed. Some brief considerations of gravity assist for rendezvous are, however, presented.

Report P-7

"Scientific Objectives of Deep Space Investigations - Venus"

P. J. Dickerman

June 1966

A review of our present knowledge of Venus suggests that it is a scientifically interesting planet for early detailed exploration by a space probe. The interest is due to a variety of reasons, but arises primarily because of the apparently totally different nature of its atmosphere as compared to those of Mars and Earth, our lack of understanding of the atmosphere and surface conditions, and the controversies due to conflicting data. No single area of study has yet been investigated completely, so that much additional data are required to complete our understanding of this planet.

A general description of Venus based on results of past experiments can be summarized briefly in the following statements. The planet is very similar to the Earth in mass, size, and density, so much so that it can be made to fit almost any theory for the interior structure of the Earth. It is widely held that Venus is chemically equivalent to the Earth, having a distinct iron-rich core with a central pressure of roughly one megabar. The surface seems to be at a temperature of 700°K, with a pressure exceeding 10 atm and possibly reaching 100 atm. Any liquid areas that do exist are probably small, and may be expected to be turbulent oceans of hydrocarbons.

CO_2 is the only atmospheric constituent whose identification is at present undisputed, but it apparently comprises less than 10 percent of the atmosphere. Disputed identifications have been made for O_2, N_2, H_2O, H_2CO and CO. Negative results were obtained in searches for N_2O, CH_4, C_2H_6, and NH_3. The composition of the clouds is unknown; the most that can be said is that the upper portions consist of fine droplets or dust. If Venus has a magnetic dipole field, the diple moment is less than 0.1 that of the Earth's. The existence of Venusian charged particle radiation belts is uncertain.

A detailed evaluation of this current knowledge indicates that answers must still be found for a great many questions. These answers are of importance beyond the additions they would provide to our present knowledge of Venus. In particular, studies of the very dense atmosphere may lead to a better understanding of the evolution of planetary atmospheres and planetary physics in general. Further, despite the apparent extreme surface conditions, Venus is still biologically interesting, since life forms may exist in suspension at various levels of the atmosphere and because of the possible existence of localized, highly elevated, cooler surface regions.

The measurements which are suggested for missions to Venus may be briefly categorized as follows:

1) Ultraviolet, infrared and radiometric observations for determination of atmospheric constituents, atmospheric circulation, and planetary energy

balance. Polarimetry may be incorporated for cloud layer studies.

2) Microwave radiometry to provide detailed thermal profiles and to establish accurate brightside and darkside temperature values.

3) Radar measurements to obtain detailed topographical information.

4) Magnetometry and charged particle counting for a precise definition of the Venusian magnetosphere.

5) Direct lower atmosphere and surface measurements using an atmospheric entry probe. Included are pressure, temperature, density and surface composition determinations.

6) Biological experiments for detection of bio-molecules, life forms, or evidence of life in the past.

Report P-10

"Critical Measurements on Early Missions to Jupiter"

J. M. Witting, M. W. P. Cann, and T. C. Owen

December 1965 NASA STAR N66-15807

Existing knowledge of Jupiter's magnetosphere, ionosphere, atmosphere, and interior is summarized, and critical measurements which can be made from flyby missions to Jupiter are indicated.

Studies of radio emission have indicated the presence of a sizable magnetic moment and radiation belts of energetic electrons. Estimates place Jupiter's surface magnetic field strength at about 10 gauss, and indicate the presence of radiation belts, similar to the Earth's in configuration, but with particle densities about 1000 times greater than the Earth's. These estimates are probably correct to within an order of magnitude. The magnetosphere extends to at least 40 Jupiter radii at the subsolar point.

The presence of an ionosphere has been deduced theoretically, assuming a model atmosphere. Primarily because of lower solar radiation flux and small recombination cross sections, the theories predict lower ionization and recombination rates on Jupiter than on Earth. The resulting concentrations of electrons are estimated to peak at about 10^6 electrons/cm^3 at about 200 km above the cloud tops.

Three constituents have been identified in Jupiter's atmosphere by spectral observation. Hydrogen is known to be present in large quantities though the actual amount of hydrogen is quite uncertain at present. Amounts of methane (150 meter atmospheres) and ammonia (7 meter atmospheres) are small. Based on cosmic abundance arguments, large amounts of helium should also be present, with smaller amounts of neon.

The temperature in the Jovian atmosphere has been measured at various wavelengths in the microwave and infrared regions of the spectrum. The temperatures obtained ($\simeq$ 150°K) are somewhat higher than the blackbody temperature for the planet (93°K - 131°K). They fluctuate over a range from 125°K to 200°K in the wavelength range 8μ to 3 cm, indicating that the observed thermal emission at the different wavelengths comes from different depths in the atmosphere.

Model studies of Jupiter's interior have indicated the possible presence of metallic hydrogen and a high density core near the center of the planet. Large errors may be present in calculated densities, because of the lack of knowledge of the equation of state for hydrogen and helium under pressures calculated (up to 10^7 atmospheres), which lie above terrestrial measurements (up to 2×10^4 atmospheres).

The magnetosphere, atmosphere, and interior of Jupiter are of primary scientific interest at this time. Although properties of the magnetosphere and atmosphere can be measured relatively directly by a spacecraft, the interior is inaccessible to direct measurements. Useful gains in knowledge of the interior are possible, however, from inferences that can be drawn from a better knowledge of the magnetosphere and atmosphere. Eleven measurements which are feasible now or in the near future are suggested for early missions to Jupiter. Most are directly concerned with Jupiter's magnetosphere or atmosphere. Parameters measured would be: 1) magnetic field strength and orientation, 2) flux of 40 kev electrons, 3) flux of relativistic electrons, 4) flux of energetic protons, 5) atmospheric and ionospheric scale heights, 6) ionospheric electron density profiles, 7) emission spectra from 1000-7000 Å, 8) H, He, and Ne line strengths under high resolution, 9) temperature at 10-13μ, 10) temperature at 7 mm, and 11) polarization of reflected sunlight.

It is concluded that:

1. A modest number of experiments carried out on a spacecraft fly-by mission to Jupiter can significantly add to present knowledge.
2. The distance of closest approach to Jupiter can be quite large,up to 40 R_J, for significant yields from some of the most important experiments. For magnetospheric studies, step functions in information level occur for penetration within 6 R_J and within 3 R_J.
3. Trajectory requirements for a particularly desirable mission are quite reasonable, requiring an ideal velocity of 54,000 ft/sec and a time of flight from Earth to Jupiter of 500 days.

Report P-11

"Scientific Objectives of Deep Space Investigations - Saturn, Uranus, Neptune and Pluto"

P. J. Dickerman

January 1966

This document reports a study performed by the Astro Sciences Center of IIT Research Institute on the scientific objectives for the four outermost planets: Saturn, Uranus, Neptune, and Pluto. Jupiter, often included in descriptions of outer planets, has been treated independently and so is not discussed in detail at this time.

The four outermost planets, with the possible exception of Pluto, differ radically in many respects from those nearer the Sun. The differences are shown in this report in a general survey of the structure and composition of these planets and in more detailed discussions of the individual bodies. It is seen that models for the planetary interiors are necessarily rather incomplete at the present time, while descriptions of the atmospheres have been carried somewhat further along, primarily with the aid of spectroscopic and radiometric observations. Some of the better known characteristics are included in the table at the end of the summary. Much of the data is only qualitative at this time, however, so that the potential for experimental investigations using space probes is very great.

In particular, missions to these planets will allow the species concentration and distribution within the atmosphere to be tentatively established. Observations can determine the ammonia content of the Saturn atmosphere and also yield a value for the hydrogen-helium ratio on Uranus and Neptune. Such information, along with temperature measurements, will provide for an understanding of the energy balance throughout the atmospheres and, to a lesser extent, within the bodies of the planets. The magnitude and configuration of the planetary magnetic fields will also represent significant new knowledge, as will the determination of the presence or absence of ionospheric and auroral effects.

Observations from a spacecraft could further provide some understanding of the belts, spots, zones, and other features which have been observed on Saturn. The origin of the nonthermal radio noise from this planet might be explained. It may also be possible to determine the exact nature of the particles in the ring system.

Since Uranus and Neptune are very far from Earth, there does not yet exist much detailed information of atmospheric features or content. Thus many things would be measured for the first time. One such important determination would be the mean molecular weight of their atmospheres. As for Pluto, so few facts are known that just the determination of its mass and diameter would represent meaningful experiments.

The measurements which are proposed are: 1) magnetic field measurements throughout the mission and in the region of the planets, 2) spectrometry and polarimetry of the planetary atmospheres, 3) microwave radiometry and radar probing, 4) charged particle detection in trapped radiation belts, 5) optical occultation experiments for Saturn's ring system and atmospheric studies, 6) RF occultation experiments for atmospheric density determinations, and 7) photography of cloud structure and, where possible, surface features of the planets.

SUMMARY OF PHYSICAL PROPERTIES

Planet	Atmosphere Known Constituents and Estimated Temperature	Interior Principal Constituents	Additional Features of Interest
Saturn	Ammonia, methane, and hydrogen 90°K-100°K	Primarily hydrogen and helium	Has the only satellite (Titan) on which an atmosphere has been observed
Uranus	Methane, hydrogen 70°K-80°K	Ammonia, methane, and water	Axis of rotation lies practically in ecliptic plane.
Neptune	Methane, hydrogen $T \approx 70°K$	Ammonia, methane, and water	Has large satellite (Triton) which is in retrograde motion.
Pluto			Estimate of diameter ($\approx$ 6000 km) is the only physical data for this planet.

Report P-14

"Analytical Methods and Observational Requirements for Interpretation of Asteroid Distributions"

J. Ash

June 1966 (in publication)

In this report, the significance of the distribution of the asteroids is considered. Questions are raised whether ordering mechanisms exist capable of arranging the asteroids in some identifiable distribution, or whether the asteroidal material is more or less randomly distributed throughout an essentially toroidal ring extending from Mars to Juputer. The conclusion is reached that the planets, in particular Jupiter, exert small perturbing forces, which over long periods of time produce distinctive distributional features. These features are deterministic, and through suitable interpretation, the mechanical history of solar system events may possibly be traced back through time and contribute to the understanding of the solar system origins. The deeper understanding of distributional features can also be of value for the prediction of possible hazards to interplanetary space missions.

The purpose of this report is twofold: (1) to outline general methods of analysis for the interpretation of asteroid observational data and their significance, and (2) to recommend further observations to extend and support existing hypotheses and theoretical approaches. A summary list of recommended observations, from space probes and Earth based, is presented in the following table.

TABLE OF RECOMMENDED OBSERVATIONS

Observation	Specific Requirements	Purpose
Number and size of distribution (in ecliptic plane)	1) In neighborhood of a libration point	Determine possible clustering Test hypotheses for stability analyses
	2) In neighborhood of a resonance with Jupiter period	
	a) Inner & central regions of asteroid ring	Test hypotheses & methods of celestial mechanics that now predict V-shaped number distribution
	b) Outer regions of ring	Determine if clustering occurs & the extent of influence of higher order commensurabilities
	3) Through a continuous range of smaller sizes	Test comminution laws & establish semi-empirical coefficients for fragmentation processes
Distributions out of the ecliptic	1) Orbital eccentricities	Test evolution hypotheses regarding plasma condensation processes
	2) Orbital inclinations	Test poorly convergent perturbation techniques for secular variations of higher inclination orbital elements
		Determine dispersion and relative velocities of eroding particles from asteroid surfaces
	3) Motion of perihelion	Understand motion of apse line for higher inclination orbits; also of significance to motion of comet orbits and relation to meteor streams.

Observation	Specific Requirements	Purpose
Orbital elements	1) For smaller members of recognized families	Provide a more adequate statistical model
		Correlate spread in parametric values with the initial collision scatter velocities to provide estimates of family age
		Permit determination of proper values for families
	2) More accurate measurements of members of a selected family	Extend validity of computations of secular variations over greater time interval
Orbital directions		Provide evidence relevant to cometary origins
Axial rotation and direction		Evidence of origins: collision fragments or primordial condensations
Surface physical	1) Reflectivity	Correlation with Earth-based observations and uniformity indicates non-fragment
	2) Roughness	Indicates collision fragments
	3) Erosion	Age indicator
	4) Craters	Impact history
Material physical and chemical properties		Provide impact parameters for collision mechanics
		Comparison with recovered meteorites to establish meteorite origins

Observation	Specific Requirements	Purpose
Material physical and chemical properties (Cont'd)		Comparison with comet core
		Age estimates
		Collision history

Report P-16

"Measurements Related to Exobiology on Venus"

W. H. Riesen and D. L. Roberts

June 1966 (in publication)

It is now generally accepted that the origin of life was a natural, perhaps inevitable, step in the evolution of the Earth. The recent progress in cellular biology and biochemistry has provided a significant, but by no means complete, understanding of the evolutionary processes from the first simple cells to the diverse and complex life forms at present abundant on the Earth. The suggestion of life on planets other than the Earth, has been applied, in the past, almost exclusively to Mars and has resulted in Mars being designated as an ecological preserve. However, over the last few years there has been an increasing awareness that life or pre-life forms may exist elsewhere in the solar system and in the universe. Life can be defined simply as "something that is capable of storing information, replicating, and controlling the transfer of energy." However the recognition of life, in all possible forms, is by no means simple and is certainly not constituted by the recognition of complex molecules that are often associated with living forms.

For life to persist on the Earth there are certain fundamental requirements which include liquid water; an atmosphere containing oxygen and carbon dioxide; temperatures between about 0°C and 80°C; pressures between some

1000 and 0.5 atmospheres; sources of food as organic compounds or carbon dioxide; and an energy source of sunlight, heat or chemical energy. In addition an early reducing environment must be available for the development of the first single cells and any changes in the environment should be slow enough to sustain life as it increases in complexity. An examination of conditions on Venus indicates that life is possible there at least in localized biotic zones on the surface or in the atmosphere. It thus is pertinent to develop an ordered sequence of biological exploration which will answer the question as to whether life has, does or could exist on Venus.

The suggested sequence of exploration is to first adequately define the Venusian environment to determine the location of possible biotic zones. This phase should include a determination of the atmospheric temperature and pressure profile, the topographic features of the surface, the constitution of the atmosphere, the locations of liquid water, the radiation levels as a function of altitude and the spatial distribution of solid or icy particulates in the atmosphere.

This data should allow an identification of possible biotic zones on Venus. Within these zones it is important to then measure the distribution of any hydrocarbons, amino acids or other complex organic compounds using gas chromatography and mass spectrometry. As a final phase in the biological exploration, direct life detection methods should be used in those zones, if any, where past or present life seems most probable.

Report S-2

"Scientific Questions Requiring Advanced Technology: Asteroid Fly-Through Mission"

J. A. Greenspan

April 1966

This report defines technical areas in which the development of instrumentation and instrumental techniques are required for satisfying the scientific measurement requirements of an asteroid fly-through mission. The particles contained in the asteroid belt were divided into five size ranges; namely, the sub-micron, micrometeorite, sub-millimeter to 3-cm, 3-cm to 1-km, and greater than 1-km diameter, for convenience in considering the scientific questions and appropriate measurement techniques. The scientific questions concerning the spatial distribution, structure and composition of each size class were formulated. Existing and proposed experimental techniques were then examined for each class and instrumental areas requiring technological advances were defined.

Only two technical areas appeared to be adequately covered by existing instrumentation, micrometeorite detection and visual observations. Several other technical areas are defined which could be satisfied by modest development programs. Five specific requirements for advanced technology were derived from this study:

1. A direct technique for simultaneously determining the mass, size, velocity, position and direction

of a statistically significant sample of sub-micron size particles throughout the asteroid belt.

2. A remote technique for simultaneously determining the mass, size, velocity, position and direction of a statistically significant sample of sub-millimeter to 3-cm diameter particles throughout the asteroid belt. The instrumentation requirements here differ markedly from those in item (1).

3. A technique for collecting particle samples in the asteroid belt. The particles must be collected partially intact for structural studies while the collection of vapors may suffice for compositional studies. Collected samples may be analyzed onboard or returned to Earth for laboratory analysis.

4. A remote technique for determining the structural characteristics of particles in the asteroid belt.

5. A remote technique for determining the composition of particles in the asteroid belt.

Of these, the first three should receive early attention.

Report S-3

"Telemetry Communications Guideline"

M. Stein

June 1966 (in publication)

There is clear evidence that the ability to send exploratory spacecraft from Earth to remote portions of the solar system has exceeded the present capability to communicate with these vehicles in all but a marginal sense. This situation is one which unfortunately could become characteristic of nearly all future space missions; it arises from the fact that, once sent on its way, an outbound spacecraft can continue onwards with very little expended energy, while the required communications power must increase as the square of the range. It is for this reason that continual effort is being spent towards increasing the capabilities of the telemetry, tracking and command systems.

This report considers only one aspect of deep space communications; namely, the information transfer capability of the telemetry system. The first section of this report considers the major limitations to a communication system. Also included are the present and projected performance capabilities for the various subsystems, such as antennas, transmitters, and receivers. Using the physical constraints as provided, a set of generalized telemetry communication guideline curves are provided for use in determining the maximum attainable data rates transmitted from a spacecraft as a function of transmitter power and distance from the Earth.

A section on an optimum telemetry transmitting system is presented and shows how the weight constraints of the spacecraft's telemetry equipment may be optimized with respect to the antenna size and transmitter power level. The specific weights as assigned to the various subsystems were based on both present and projected figures. The specific weight for attitude control propellant was not included as part of the analysis, therefore the curves only provide a first approximation for the design of a spacecraft's telemetry system.

Report T-17

"Low-Thrust Trajectory Capabilities for Exploration of the Solar System"

A. L. Friedlander

June 1966 (in publication)

This report presents the trajectory energy requirements for low-thrust flight throughout the solar system, first for the general class of flyby missions to points in and above the ecliptic plane, and then for flyby, capture and orbiter missions to the planets Mercury through Pluto. The trajectory energy requirements are described in terms of the parameter "J" (defined as the time integral of thrust acceleration squared). Application of results contained herein is mainly to electric propulsion systems operating at a constant power level.

Results for the general flyby missions are presented as accessible regions contours of J and flight time. The accessible regions concept provides a convenient graphical means of characterizing and comparing the performance capability of different vehicle systems and modes of propulsion. Results for the planetary missions are presented as graphs of J vs flight time. The payload/flight time capabilities of two conceptual nuclear-electric spacecraft designs are illustrated in terms of the accessible regions graph and summarized for each of the planetary missions.

Application of electric propulsion systems to upper stage space vehicles is shown to offer a high performance potential for carrying out a long-range plan of solar system exploration. This performance potential (large payloads and reduced flight time) is particularly in evidence when the mission energy requirements are very high. On the basis of results described in this report and previous comparisons between ballistic and thrusted flight, the most attractive applications of electric propulsion are identified with solar probes, out-of-the-ecliptic probes, Neptune and Pluto flybys, minimal capture orbiters at Uranus and beyond, and low altitude circular orbiters about all the outer planets.

2.2 Technical Memoranda

Technical Memorandum M-8

"Cometary Study by Means of Space Missions"

D. L. Roberts, F. Narin, and P. M. Pierce

August 1965

Intercept missions have been selected from an analysis of 110 periodic comet perihelia between 1965 and that of Halley in 1986. Consideration has also been given to intercepting first apparition comets. The selection criteria include predictability of their future returns, ability to obtain spectroscopic data from Earth during intercept, and space flight limitations of launch energy, experimental capability and spacecraft compatibility. Cometary intercepts between 1000 and 10,000 km from the nucleus are anticipated. The scientific value of the five missions selected is discussed together with the influence of the flight parameters on the spacecraft payloads.

Technical Memorandum M-10

"The Satellites of Mars"

D. L. Roberts

November 1965

The satellites of Mars, Phobos and Diemos, are difficult to observe from the Earth because of their small size, their closeness to Mars and their faintness compared to Mars itself. The limited data extends only to approximate orbital elements and estimates of their size and mass. There appears to be a secular variation in the orbital elements of the inner satellite, Phobos, which is causing its orbit to decay, but the orbit of Diemos seems comparatively stable.

The most important information which should be obtained on the satellites is quite basic. Accurate orbital elements should be determined, the sizes measured, and the surface characteristics observed. A second accurate determination of the orbital elements after an interval of two years or more, should enable any secular variations in the elements to be calculated. It is probable that only space missions can provide the required data.

Without an accurate knowledge of the orbits of the satellites, and their positions in their orbits, it would seem that a detailed study of rendezvous missions to Phobos or Diemis is unwarranted. Rather it is suggested that orbiting missions to Mars should be used to obtain the necessary basic data on which a detailed study can be based.

Technical Memorandum P-12

"Regularities in the Solar System Pertaining to its Origin and Evolution"

J. Witting

January 1966

The boundary conditions on theories of the origin of the solar system and its evolution which arise because of regularities in the solar system have been studied.

The Sun's angular momentum, though only a small fraction of that of the entire solar system, is compared to that of other stars. No differences have been found between the Sun's angular momentum and that of other stars of the same spectral class. Furthermore, in direct observations comparisons to nearby stars which have masses comparable to planets, and multiple-star systems with interstellar distances of the order of 20 AU are common. These facts suggest that planetary systems are probably quite common, and lead to the conclusion that the existence of some unusual event postulated by many of the older theories for planetary formation is unwarranted from the evidence now at hand.

The inclinations and eccentricities of planets and asteroids are found to be very low, all inclinations being less than 16°, the majority being less than 2° and all eccentricities being less than .25, the majority being less than .06.

Nineteen of the thirty-one known planetary satellites have extremely low inclination ($< 2°$). These also have low eccentricities ($< .11$). If satellite and planetary systems are formed by similar processes, the importance of low planetary inclinations and eccentricities is enhanced. A theoretical study indicates that the inclination and eccentricity of an orbit is probably fairly stable against gravitational perturbations and mass-changes over a time scale of the order of the age of the solar system. It is concluded, therefore, that the regularity of low planetary and asteroidal inclinations and eccentricities is a boundary condition for a theory of solar system origin, unless perturbations of a type not considered here act to regularize inclinations and eccentricities.

The Titius-Bode "law" indicates some regularity between planetary semi-major axes. "Titius-Bode law" for satellites of planets shows less regularity. The Titius-Bode law is, therefore, a weak boundary condition on theories of the origin and evolution of the solar system.

Planetary longitude of ascending node and longitude of perihelion show no regularity. It is shown that gravitational perturbation would modify any possible order in a random fashion over five billion years. Therefore, little or no information about the origin of the solar system is preserved in the longitudes of ascending node or perihelion of the planets.

Most planets have relatively low ($< 30°$) inclinations between their equatorial plane and their orbital plane (Venus and Uranus are glaring exceptions). This is a regularity, but not a strong one. On the other hand, centrally located objects in the solar system (the asteroids, and all planets from Earth to Neptune) rotate on their axes with rotational periods which are remarkably similar, varying from object to object by no more than a factor of five. This similarity in rotation periods is considered a boundary condition either for a theory of the origin of the solar system or of its evolution.

Gross physical properties of the planets, such as mass, density, atmospheric mean molecular weight, and composition have been compared. It is shown that the terrestrial planets, Mercury through Mars, have similar properties, as do the Jovian planets, Jupiter through Neptune. On the other hand, there is a great difference in the gross physical properties of a terrestrial planet and a Jovian planet. It is shown that the similarity in the gross physical properties of members of a planetary group, and the difference between the groups, might depend only on whether or not a planet can retain hydrogen and helium over the lifetime of the solar system. Each Jovian planet can retain hydrogen and helium; no terrestrial planet can. This implies that the regularity in the gross physical properties of the planets might have come about in an evolutionary fashion after the origin of the solar system. The regularity is, therefore, shown to be a boundary condition on theories of the evolution of the solar system, but not of its origin.

Finally, it is shown that a conspicuous lack of mass in the solar system is present between about 1.3 and 4.0 AU. The existence of this "mass gap" is another boundary condition for theories of the origin and evolution of the solar system.

Further studies are planned which will consider boundary conditions on theories for the origin and evolution of the solar system which are not regularities, such as dating and isotope ratios, among others. After a study of proposed theories, we expect to be able to define useful new spacecraft experiments critical to the question of the origin and evolution of the solar system, and to determine the relevance of presently proposed classes of experiment.

Technical Memorandum P-13

"Comparison Criteria for a Total Lunar Scientific Exploration Study"

Astro Sciences Center

February 1966 (copies not available)

The Office of Space Science and Applications has been asked to participate in a review and study of the NASA program for lunar exploration. This technical memorandum has been prepared as a quick response to a request for a set of comparison criteria for the review and analysis of the lunar exploration programs.

In the comparison of missions, most of the criteria can be simply stated but the detailed considerations and problems that arise in applying a set of criteria are not always immediately obvious. Four basic a priori groundrules are suggested: (1) a decision must be made whether to include or exclude ground support costs, (2) the allocation of payload fractions and fractional costs must be standardized for those missions with a multiplicity of goals, (3) a uniform method of predicting costs must be established, and (4) a basic method for predicting and applying advances in technology must be developed.

Three categories of criteria are discussed briefly. The scientific criteria are discussed in terms of their priority, clear definition, complementarity and success probability. The spacecraft criteria are discussed in terms of universal definitions of system and subsystem configurations. The operational criteria are discussed in terms of scheduling, cost factors, areal coverage, terrain constraints, reliability and the role of safety of man.

Technical Memorandum T-16

"Selection of Comet Missions: 1965-1986"

F. Narin, P. M. Pierce, and D. L. Roberts

September 1965

The selection of missions to both short period, well-known comets, and long period, first apparition (new) comets, was considered for the time period 1965-1986. Short period comet missions are easier in the sense that one can plan for them in advance. However, only a few of the well known short period comets are bright enough to be of interest for a mission. On the other hand the long period comets are more active and, on the average, 3 magnitudes brighter than short period comets. Potentially there are many opportunities for good missions to new comets. However, selection of new comet missions is complicated since there is no prior knowledge of when the probe can be launched, and because there is not yet a systematic comet discovery program.

The following selection criteria were imposed for the short period comet missions:

1. Two recent passes observed
2. Brighter than magnitude 12 at intercept
3. Recovery two months before launch of spacecraft
4. Recovery magnitude brighter than 20, with two hours visibility in a dark sky
5. Energy requirements less than those for a two year Jupiter mission.

Of 37 comets considered with 110 apparitions between 2/65 and 1/86, 93 were eliminated on brightness-energy considerations, leaving 17 possible missions. Of these 5 were selected missions and 12 were considered to be of secondary interest. The 5 selected missions were Temple 2, 1967; Encke, 1974; D'Arrest, 1976; Kopff, 1983; Halley, 1986.

To assess the feasibility of new comet missions all of the new comets which were discovered between 1945-1960 were analyzed to find which ones would have made interesting targets. Of the 54, new long period comets discovered, only 2 would have made suitable targets after discovery, using the same brightness energy criteria as used for short period comets. However, if all of the new comets were discovered at magnitude 15 by a comet search program, 10 missions or one every 1.5 years would have been possible. From this it may be concluded that missions to new, long period comets should be possible if a systematic comet search program were initiated.

3. TECHNICAL NOTES

3.1 Prospectus 1966

Considerable assistance has been provided to NASA in the preparation of the OSSA Lunar and Planetary Programs Prospectus for 1966.

Many iterations were provided on the mix of missions which could constitute the exploration plans for the next twenty years and seven initial plans were generated for consideration. The differences in the plans were principally related to budget constraints, which were reflected in the emphasis given to the exploration of the near planets, distant planets, comets and asteroids. In many cases the modes of exploration (flyby, orbiter, probes, etc.) are dependent on the budget constraints and thus may comprise the ability of the plans to adequately fulfill the scientific objectives.

The seven initial plans were reduced, by selection, to two basic exploration plans, the one constrained to a level budget and the other allowing a 7% to 12% budget increase per year.

The plans call for the institution of two new spacecraft projects, Advanced Planetary Probe (APP) and Advanced Planetary Voyager. Both projects are essential to an orderly progression of scientific missions and a technologically feasible sequence of missions, particularly to the outer reaches of space.

Contributions were made in the definitions of the scientific objectives, the communications requirements, the payload weight compilations, the generation of mission flight parameters, and the rationale for mission requirements. The nature of the effort required a quick response in the solution of all problems which arose throughout the formulation of the mission plans. A series of mission definitions were compiled and each was supported by a series of mission fact sheets. The missions covered ranged from a simple asteroid fly-through to a Voyager-type orbiter of Saturn.

3.2 Asteroid Movie.

A computer generated movie simulating the motion of the asteroids was created to dynamically study the phenomena of clustering within the asteroid belt. The movie shows 1563 asteroids as they would appear to an observer looking down from 10 AU above the Sun, and covers the years 1965 through 1979. Observation of the movie clearly shows the formation and disintegration of clusters within the asteroid belt; to date no particular pattern has been discerned for the clustering. The movie does give the viewer a very vivid comprehension of the extent and motions of the asteroids within the asteroid belt.

3.3 Space Mission Slide Chart

The slide chart has been prepared and is now being manufactured. It enables the launch energy, payload and flight time to be determined for a very wide variety of flyby flights throughout the solar system. Both direct ballistic and nuclear electric low thrust flights are covered. The slide chart is pocket size and will be very useful for preliminary mission planning. It is based on the accessible regions method which was developed for presenting trajectory data for flyby interplanetary flights.

3.4 Preliminary Outline of a Planning Methodology for Total Lunar Exploration (copies not available)

This document is provided in response to a request by the Lunar Exploration Working Group at NASA Headquarters. A methodology and logic is suggested which enables the basic lunar scientific questions to be interpreted in terms of an exploration plan. The starting point is the expression of the scientific questions in terms of the lunar parameters which must be measured and the techniques available for making the measurements. Of great importance at this point is the specification of the minimum number of lunar sites (a site may embrace more than one feature) at which each measurement must be made. The techniques and their associated site requirements are then listed in priority order in terms of their ability to contribute to total lunar exploration. This priority listing involves value judgments as to the importance of each scientific question and the significance of the techniques in answering the questions.

The methodology now applied is to consider only the few highest priority techniques and to assign them individually to the most suitable mission concept. Thus a minimum number of basic missions become established. Lower priority techniques are then allocated to the most suitable of these missions until their capabilities are filled, and only then are further missions added.

The report provides examples of this methodology and two sample mission plans are developed, one biased towards manned exploration and the other towards unmanned exploration.

3.5 Operational Computer Codes

The following are the main computer codes which have been added to the Astro Sciences Center's program inventory during the last year.

3.5.1 The Evaluation Code

This code has been written to evaluate the intrinsic scientific value of various lunar or planetary exploration plans. The code assigns a specific value to each mission and to each target, takes into account to some extent the variation in value of repeated missions to a single target, and comes out with a total value for the given plan, and also a division of that value into specific scientific areas. The first version of the program is being tested and will be expanded with use.

3.5.2 Topsy

For any point in a three-dimensional solar system, this code automatically determines the minimum ideal velocity and the corresponding time of flight required to reach that point from the Earth. The code also determines minimum ideal velocity for constant times of flight.

3.5.3 Limits

Using maximum velocity and maximum energy change equations for gravity assist, this code computes these changes as a function of miss distance from the desired gravity assist body. Usage is applicable to both planets and planet satellites

Auxiliary information about specified trajectories is also provided by the code for the maximum energy case.

3.5.4 Hyptrc

This code is used to compute 2-D planetary encounter trajectories given a heliocentric transfer trajectory from Earth. The output data provides a polar plot of the encounter trajectory with the zero direction being the velocity vector of the planet. The information presented for each trajectory point includes the polar coordinates, velocity and the time with respect to periapsis.

4. SPECIAL STUDIES

4.1 Survey of Bioclean Facilities

The future space exploration program will require a significant number of sterile spacecraft. An essential phase in the production of these sterile spacecraft will be their assembly in bioclean facilities, and preferably in qualified existing facilities rather than in structures specifically constructed for this purpose. Under Contract No. NASr-65(06), IITRI conducted a survey of a selected cross section of presently operating, contamination controlled areas to determine the requirements for their conversion to bioclean rooms for the assembly, checkout, and decontamination of small spacecraft.

This final report is issued in three volumes.

Volume I - Guidelines for Evaluation, Conduct of Survey, and Cost Estimation for Modifications

Volume II - Overall Conclusions, Recommendations, and Summaries of Individual Facilities

Volume III - Detailed Results and Evaluations of Individual Facilities.

Volume I will be made available generally. Volumes II and III will be restricted to use by NASA personnel only.

4.2 Report R-2

"Probability of Biological Contamination of Mars"

A. Ungar, R. E. Wheeler, and D. L. Roberts

March 1966

There is a firm commitment to NASA to make the risk of contaminating Mars very small while at the same time the sterilization levels sufficient to meet such a risk must also be minimized. In this connection IIT Research Institute (IITRI) has undertaken a study of the probability of biological contamination of Mars. In particular, the model proposed by Sagan and Coleman* has been critically reviewed and an independent IITRI contamination model has been generated.

The Sagan and Coleman paper contributes two inputs to the problems of the contamination of Mars. It provides a formulation of the probability of contamination for a series of experiments which continue until satisfactory answers have been obtained on the questions of Martian biology. It also provides an illustrative computation of the required overall probability of contamination to support such a series of experiments by inserting in the equation an assumed value for each parameter. The computation is a single example and no indication is given of how the result would vary if different values were assumed.

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*Sagan, C. and S. Coleman 1965, Spacecraft Sterilization Standards and Contamination of Mars, Astronautics and Aeronautics, May.

The IITRI model has been derived from an entirely different approach to the problem of contamination. A mission' profile has been assumed for the flight, from launch on Earth to intercept at Mars. A range of probabilities has been assigned to each event in the mission and an overall probability of contamination per mission has been derived parametrically.

The IITRI model is presented as an alternative to, not a replacement for, the Sagan-Coleman model in guiding the decisions which must ultimately be made by NASA regarding the risk of contamination of Mars which will be accepted and the commitments which will have to be made in adhering to the specified risk.

5. PAPERS PRESENTED AND PUBLISHED

The following are the technical papers presented and published since July 1965 as a result of work performed under the contract.

5.1 An Analysis of Gravity Assisted Trajectories to Solar System Targets

Presented at the 3rd Aerospace Sciences Meeting
January 24-26, 1966 — J. C. Niehoff

To be published in the Journal of Spacecraft and Rockets.

5.2 Spatial Distribution and Motion of the Known Asteroids

Presented at the 3rd Aerospace Sciences Meeting
January 24-26, 1966 — F. Narin

To be published in the Journal of Spacecraft and Rockets.

5.3 Cometary Study by Means of Space Missions

Presented at the 13th International Astrophysical Symposium
July 6, 1965 — D. L. Roberts

To be published in the proceedings of the symposium and in the Memoires de la Societe Royale des Sciences de Liege.

5.4 Low-Thrust Trajectory and Payload Analysis for Solar System Exploration

Presented at the AIAA Fourth Aerospace Sciences Meeting
June 29, 1966 — A. L. Friedlander and F. Narin

5.5 Satellite Roles in Radio Emission from Jupiter

Presented at the 120th Meeting of the American Astronomical Society
December 27-30, 1965 — J. Witting

6. BIBLIOGRAPHY OF ASC/IITRI REPORTS AND TECHNICAL MEMORANDA

The following bibliography of ASC/IITRI reports and technical memoranda includes all those published since the beginning of the contract in 1963.

TM C-3 An Empirical Approach to Estimating Space Program Costs, by J. Beverly, C. Stone and R. Vickers (copies not available)

R C-4 Progress on Spacecraft Cost Estimation Studies, by J. Beverly and C. Stone (copies not available)

TM C-5 An Analysis of the Correlation between Spacecraft Performance and Cost Complexity Factor, by W. Finnegan (copies not available)

R C-6 Spacecraft Cost Estimation, by W. Finnegan and C. Stone

R C-7 Spacecraft Program Cost Estimating Manual, by W. Finnegan and C. Stone

R M-1 Jupiter Mission Study, by ASC staff, NASA STAR No. N64-20643

R M-2 Survey of a Jovian Mission (U), Confidential (copies not available)

R M-3 Survey of Missions to the Asteroids, by A. Friedlander and R. Vickers, NASA STAR No. N64-19566

R M-4 Summary of Flight Missions to Jupiter, by ASC staff, NASA STAR No. N64-26597

R M-5 Missions to the Asteroids, by ASC staff (copies not available)

R M-6 A Study of Interplanetary Space Missions, by D. L. Roberts, NASA STAR No. N65-25003

R M-7 A Survey of Comet Missions, by D. L. Roberts, NASA STAR No. N65-30481

TM M-8 Cometary Study by Means of Space Missions, by F. Narin, P. Pierce and D. L. Roberts (copies not available)

R M-9 Missions to the Comets, by F. Narin, P. Pierce and D. L. Roberts, NASA STAR No. N66-15978

TM M-10	The Satellites of Mars, by D. L. Roberts (copies not available)
R M-11	A Survey of Missions to Saturn, Uranus, Neptune and Pluto, by F. Narin et al.
R M-12	A Survey of Multiple Missions Using Gravity-Assisted Trajectories, by J. C. Niehoff
R P-1	Scientific Objectives of Deep Space Investigations - Jupiter, by D. L. Roberts, NASA STAR No. N64-19567
R P-2	Scientific Objectives of Deep Space Investigations - The Satellites of Jupiter, by D. L. Roberts, NASA STAR No. N64-19568
R P-3	Scientific Objectives of Deep Space Investigations - Comets, by D. L. Roberts, NASA STAR No. N64-19569
R P-4	Scientific Objectives of Deep Space Investigations - Asteroids, by D. L. Roberts, NASA STAR No. N64-19570
R P-5	Scientific Objectives of Deep Space Investigations - Interplanetary Space Beyond 1 AU, by D. L. Roberts, NASA STAR No. N64-19571
R P-6	Scientific Objectives for Mercury Missions, by T. Owen, NASA STAR No. N64-26599
R P-7	Scientific Objectives of Deep Space Investigations - Venus, by P. J. Dickerman
R P-8	Scientific Objectives of Deep Space Investigations - Non-Ecliptic Regions, by D. L. Roberts (copies not available)
R P-9	Compendium of Data on Some Periodic Comets, by D. L. Roberts, NASA STAR No. N64-28524
R P-10	Critical Measurements on Early Missions to Jupiter, by J. Witting, M. W. P. Cann, and T. Owen, NASA STAR No. N66-15807
R P-11	Scientific Objectives of Deep Space Investigations - Saturn, Uranus, Neptune and Pluto, by P. J. Dickerman, NASA STAR No. N66-17090
TM P-12	Regularities in the Solar System Pertaining to its Origin and Evolution, by J. Witting (copies not available)

TM P-13 Comparison Criteria for a Total Lunar Scientific Exploration Program Study, by C. A. Stone (copies not available)

R P-14 Analytical Methods and Observational Requirements for Interpretations of Asteroid Distributions, by J. Ash

R P-16 Measurements Related to Exobiology on Venus, by W. H. Riesen and D. L. Roberts

TM R-1 Comparative Reliability Estimation Method for Mission Programming, by H. Lauffenburger (copies not available)

R R-2 Probability of Biological Contamination of Mars, by A. Ungar, R. Wheeler and D. L. Roberts (copies not available)

TM S-1 Study of Photographic and Spectrometric Subsystems for Voyager, by P. N. Slater and G. Johnson (copies not available)

R S-2 Scientific Questions Requiring Advanced Technology: Asteroid Fly-Through Mission, by J. A. Greenspan, NASA STAR No. N66-23631

R S-3 Telemetry Communications Guideline, by M. Stein

R T-4R Summary of One Way Ballistic Trajectory Data: Earth to Solar System Targets, by F. Narin and P. Pierce, NASA STAR No. N64-19572

R T-5 Accuracy and Capabilities of ASC/IITRI Conic Section Trajectory System, by P. Pierce and F. Narin, NASA STAR No. N64-19603

R T-6 Accessible Regions Method of Energy and Flight Time Analysis for One-Way Ballistic Interplanetary Missions, by F. Narin, NASA STAR No. N64-28840

R T-7 Perturbations, Sighting and Trajectory Analysis for Periodic Comets: 1965-1975, by F. Narin and P. Pierce, NASA STAR No. N66-13398

TM T-8 Comparison of Atlas Centaur and Floxed Atlas Centaur Capabilities in Interplanetary Explorations Using the Accessible Regions Method, by F. Narin (copies not available)

R T-9 Spatial Distribution of the Known Asteroids, by F. Narin, NASA STAR No. N65-30471

TM T-10 Collected Launch Vehicle Curves, by F. Narin (copies not available)

R T-11 Sighting and Trajectory Analysis for Periodic Comets: 1975-1986, by F. Narin and B. Rejzer, NASA STAR No. N65-28347

R T-12 Analysis of Gravity Assisted Trajectories in the Ecliptic Plane, by J. Niehoff, NASA STAR No. N65-34460

R T-13 Trajectory and Sighting Analysis for First Apparition Comets, by P. Pierce, NASA STAR No. N65-35845

R T-14 Low-Thrust Trajectory and Payload Analysis for Solar System Exploration Utilizing the Accessible Regions Method, by A. Friedlander, NASA STAR No. N66-13992

TM T-15 Mission Requirements for Unmanned Exploration of the Solar System, by F. Narin (copies not available)

TM T-16 Selection of Comet Missions: 1965-1986, by F. Narin, P. Pierce and D. L. Roberts (copies not available)

R T-17 Low-Thrust Trajectory Capabilities for Exploration of the Solar System, by A. Friedlander

Appendix A

REPORT DESIGNATION AND DISTRIBUTION

Appendix A

REPORT DESIGNATION AND DISTRIBUTION

Distribution of ASC/IITRI reports is determined on the basis of range of interest or the subject matter. Those felt to be of general interest receive the widest distribution. This category includes some reports as written and digests of the long or technically detailed reports. Reports given wide distribution (see List A) are bound in red for visual identification.

Reports felt to be of more specialized interest including some mission studies and trajectory calculations are given a smaller distribution (see List B). These reports can be identified by the black binder.

Technical memoranda include results of special studies in narrow technical areas, interim reports and other documents involving very limited distribution (see List C). White binders are used to identify technical memoranda.